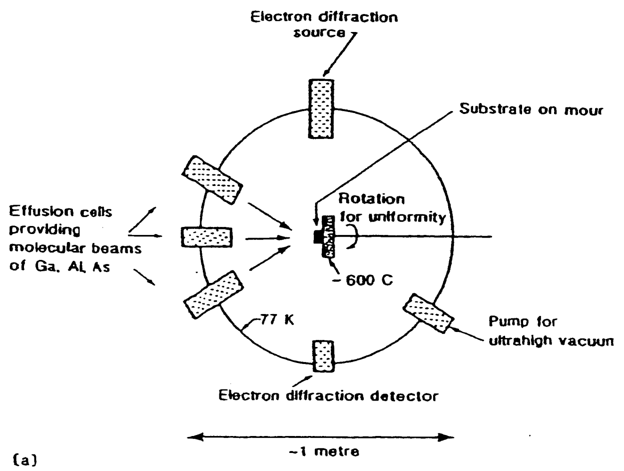
ANSWER CRIBS

Q1

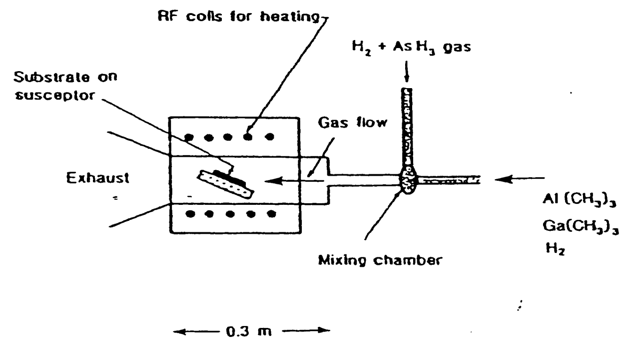
(a) Standard diagram for MBE machine and MOCVD reactor.

MBE reactor – steel sphere, 1m diameter, ultra-high vacuum pumps to 10E-11 torr, cooled to LN2, Knudsen cells on one side with elemental species, heated boats at over 1000C in come cases. Also cells with elements for doping. Shutters that open and shut in 1/10 sec. In centre of sphere, 50cm from the cells is a substrate holder, which rotates about a normal to the wafer substrate. Mention also the electron diffraction, mass spectrometer and other materials qualification instruments and the system for loading and unloading wafers. Growth process by impact of atomic or molecular beams on the wafer which is preheated to about 600C so that atomic species can migrate to steps to complete layer growth. Ga + As forms GaAs.

MOCVD reactor a horizontal glass cylinder containing a susceptor block on which the substrate is mounted at an angle to the horizontal so that the gas stream passes over the wafer substrate. A systems of gass bottles contain precursors of the elements and the dopants (trimethyl Al and Ga, arsine, silane etc) which are let out in flows diluted with a hydrogen carrier gas, these are all mixed thoroughly and let into the growth chamber in a laminar flow. The chamber is heated by an rf induction coil so that the gases can crack near the substrate surface: trimethyl GA plus arsine gives methane plus GaAs. Extract gases have to be clean up and scrubbed as they are still very toxic.



(a)



(b)

(b) MBE – one monolayer /sec	MOCVD – 10 monolayers a second
UHV system expensive	expense dominated by safety issues
Good in-situ diagnostics	no in-situ diagnostics
Later to be sued in production	early and continued production use
Better microwave devices	better optoelectronic devices

(c)

In what follows we need an explanation and diagrams of the relevant techniques.

(i) quantum well thickness

- photoluminescence (PL), about +/-1 nm
- TEM, about +/- 0.5 nm

– X-ray about +/-1 nm

(ii) Tunnel barrier thickness
- TEM, about +/- 0.5 nm
- SIMs provided there is a calibration layer: +/- 1nm

(iii) Base layer doping of HBT
- SIMS,
- resistivity (gives 2D electron density) plus thickness from TEM,

(iv) Wafer scale uniformity
- X-ray, works in scanning mode
- scanning PL.

Q2

(a) The Johnson criteria use basic materials properties, in particular the dielectric breakdown field (to establish the maximum voltage that can be placed across a piece of semiconductor material) and the saturated drift velocity of electrons (to establish the least time over which electrons can move across the same piece of material) to set limits on the behaviour of devices that depend for their operation on the transit of electrons (i.e. most electronic devices).

The two relations are $V_m f_T = (E_b v_s)/(2\pi)$

$$P\Omega(f_T)^2 = (E_b v_s)^2/(32\pi^2)$$

Where E_b=dielectric breakdown field

v_s= saturated drift velocity

V_m = maximum voltage across active volume of semiconductor device

F_T= $1(2\pi\tau)$ where τ is the transit time for electrons, and so f_T is a measure of the maximum frequency of the device,

And P is the power delivered to an output load of impedance Ω.

Using the same device structure, if the frequency rating is 10 times faster, the maximum voltage applied is 10 times smaller, and the power delivered to the same load is 100 times smaller.

(b)

Devices used as mixers or detectors have to have a non-linearity in the I-V characteristics, and in practice the most important aspect here is curvature in the I-V characteristics near the origin. In a Taylor series expansion of the I-V characteristics about a fixed bias V_0,

$$I = I_0 + \alpha(V-V_0) + \beta(V-V_0)^2 + \gamma(V-V_0)^3 + \ldots,$$

the curvature is proportional to the coefficient β in the term in the square of the difference voltage.

(c)

Four diodes that can mix signals

(i) germanium backward diode, using a reverse biased p++/n++ junction (which in forward bias would give the Esaki. This has curvature near the origin.
(ii) Schottky diode – a metal-semiconductor contact, this has maximum curvature when the diode is forward biased to the Schottky barrier height which is typically about 0.6V.
(iii) the planar-doped barrier diode which is an n-i-p$^+$-i-n diode.
(iv) the ASPAT diode (asymmetric spacer layer tunnel diode).

	(i)	(ii)	(iii)	(iv)
Frequency range,	-200GHz	- 3THz	200GHz	-200GHz
Dynamic range,	Lo	Hi	Hi	Hi
Mixing efficiency,	Lo	Hi	Hi	Hi
Noise figure,	Lo	Hi	Hi	Lo
Temperature susceptibility,	VLo	Hi	Hi	Lo
Other relevant attributes.				

Q3
(a) Si: band-gap, stable oxide, thermally grown oxide,
Not optically active and no negative differential resistance at high fields – leads to III-V devices as the key materials for lasers and microwave devices as front end devices that make entire systems possible.

(b) 0.1 micron and 1micron transistor cross-sections: see standard diagrams.

(c) The 1 micron gatelength transistor has 10^4 electrons under the gate
The 0.1 micron gate length transistor has 10^2 electrons per gate.
Therefore the 0.01 micron gatelength transistor has 1 electron per gate.
This is a decade smaller.
This would be expected to be introduced in 2015

(d) Earlier problems: cost of manufacture, complexity of design, statistical fluctuations in manufacture etc.

Q4
(a) Microwave power requires negative differential resistance in the static dc I-V characteristics of the diode as a pre-requisite.

(b) Gunn Diodes
(i) homo junction: n+ - n- - n+ typically 1μm for n+ doping layers, the n- later is typically 1.5-10μm thick depending on frequency. 1.7μm for 94GHz at 2nd harmonic.
(ii) Heterojunction: typically the same but two extra layers – a 0-30% ramp of $Al_xGa_{1-x}As$ over 50nm followed by a 10nm n+spike – these layers allow for the ramp to become flat-band under bias but still have a more moderate field

in the transit region, so as to get the maximum drift velocity for Gunn domains.

(c) Wafer – etch into mesas typically 5μm diameter and through to the bottom n+ layer. Metallise the top contact, invert into holder, thin the back of the wafer to 10μm depth and metallise and heat sink. Use a maltese cross arrangement for the top contact.

(d) Typical performance figures of a heteroj. Gunn diode over the 35-100GHz range GaAs/AlGaAs

output power:	0.5W at 35GHz	down to 0.1W at 100GHz
efficiency,	10%	2% at 100GHz
noise,	typically 10% of homojunction noise at same frequency.	
temperature sensitivity etc.	about –2% per degree C, down from 10% for homojunction	

(e) Gunn diode 100mW at 100GHz. RTD <0.1mW at 100GHz, but much more efficienct, RTD up to 20% as opposed to 2% for Gunn diode.

Q5: Gallium Nitride as an electronic material
Methods of preparation,
Levels of impurities and defects
Energy band structure – blue emitter and high-field satellite valleys
Lattice constant well away from GaAs
Growth relatively immature – MoCVD winning, witrh SiC as conducting substrate.
Johnson criteria – E_B in GaN is five times greater than GaAs
V_s is about 100% greater.
Hence $E_B V_s$ is 10 times greater than GaAs for $V_M f_T$ and 100 times for $P\Omega(f_T)^2$.
Implications for power electronic devices.
Status of HEMTS and HBTs
Status of lasers and light emitters.
Two or three extra points for first class pass.